The Northwest Fisheries Science Center

STRATEGIC RESEARCH PLAN FOR SALMON

Introduction

The mission of the Northwest Fisheries Science Center (NWFSC or Center) is to provide scientific and technical support for the management and conservation of the Pacific Northwest region's anadromous and marine fishery resources and their habitats. A key component of the scientific enterprise at the NWFSC is research on the conservation and recovery of Pacific salmon (Onchorhynchus spp.). The goal of our salmon science program is to reduce the critical scientific uncertainties in the risks salmon face and provide a solid scientific foundation for decision making by NOAA Fisheries in the Pacific Northwest. A management objective for the region is developing scientifically sound recovery plans that identify actions to reverse the marked decline in Pacific salmon populations and sustain viable salmon populations. To meet the challenge, we must better understand how ecosystem processes affect salmon biology and quantitatively evaluate and integrate effects of all risk factors on salmon survival throughout their entire life cycle. This is an essential element of the Center's salmon program. The approach to evaluating the interaction of salmon with freshwater and marine environments and the cumulative risks that salmon face from human activities is broadly organized around 10 themes to guide our research and provide a standard against which each effort can be measured. This strategic research plan contains the organizing principles for working with the NOAA regional office to prioritize the Center's short-term and long-term salmon research—from multidisciplinary programs to individual research projects.

While this plan outlines the Center's priorities for salmon research, it is important to recognize that the NWFSC is one of many organizations conducting research to improve the management, conservation, and recovery of Pacific salmon. The research needs for salmon are daunting and too large for any one research entity or organization to address. Answering questions at the appropriate scale related to these 10 research themes will require an unprecedented level of cooperation and partnerships with governmental agencies, universities, and other institutions. An essential part of this plan is strengthening our existing partnerships and forging new collaborations to carry out the research that will address management goals of NOAA Fisheries and its partners in the Pacific Northwest.

Historical and Current Context

Pacific salmon are of immeasurable cultural importance and historically supported some of the most productive fisheries in the world. Most Pacific Northwest wild salmon populations today are well below historic levels. Despite recent increases in returning adults for some populations, many are still listed as threatened or endangered under the Endangered Species Act (ESA). In an effort to recover these populations, large federal, state, and local efforts are underway to restore and protect Pacific salmon throughout western North America. While much research has been conducted on Pacific salmon, many critical questions remain unanswered. Research needs for the management and recovery of Pacific salmon are challenging in terms of the scale and the levels of effort and cooperation needed to address these questions. Our science must pose lucid questions whose answers will help provide accurate guidance to policy makers.

During its lifetime, an individual salmon can utilize habitats ranging from mountainous streams to coastal rivers, estuaries, and open oceans. The distances can be vast and the array of species with which a single salmon might interact is enormous. The many potential factors contributing to salmon declines means that we must determine in a quantitative manner the relative risk salmon populations face from multiple threats, the relative contribution of various human activities to that risk, and which specific risk reductions or eliminations will lead to recovery. We also must better understand the biology and ecology of Pacific salmon, because traditional biological and ecological theories are not sufficient for identifying population units or landscape-level processes on the scale salmon occupy. Solving the salmon conservation and recovery problem will require moving basic biological, ecological, and evolutionary theory forward.

Historically research has focused on individual risk factors or environmental variables at relatively small scales or, more recently, individual factors at a population or watershed scale. However, addressing the pressing research needs will require examining multiple factors at population, meta-population, and ecosystem scales. That will require taking full advantage of recently developed technologies —such as passive integrated transponder (PIT) tags and other tagging developments, high-throughput DNA analysis and genetic markers, and satellite remote sensing — to assist in answering important question on salmon survival, life history diversity, and population viability throughout their life cycle. Several recent modeling efforts have provided useful information and hypotheses, but all are limited by the availability and quality of existing data. It is important to note that models can be useful but are no substitute for basic physical and biological data. Clearly high quality data are needed to parameterize these models and improve their ability to predict effects of various actions on salmon survival and productivity (next generation smolt production). These data need to be incorporated into comprehensive life-cycle models that integrate the effects of different impacts (risk factors) and environmental parameters (e.g., climate) over the entire salmon life cycle.

The following sections outline research we have identified to better manage and recover Pacific salmon and help guide the salmon research efforts underway at the Northwest Fisheries Science Center. We first identify the 10 research themes and associated scientific questions that must be addressed. The themes will ultimately guide the Center's salmon research priorities and direct the development of more detailed research plans that will define focused research projects and broad-scale experiments needed to address the questions within each theme. Our thematic outline recognizes that other research agencies will have priorities that are tangential to or related to the needs we identify.

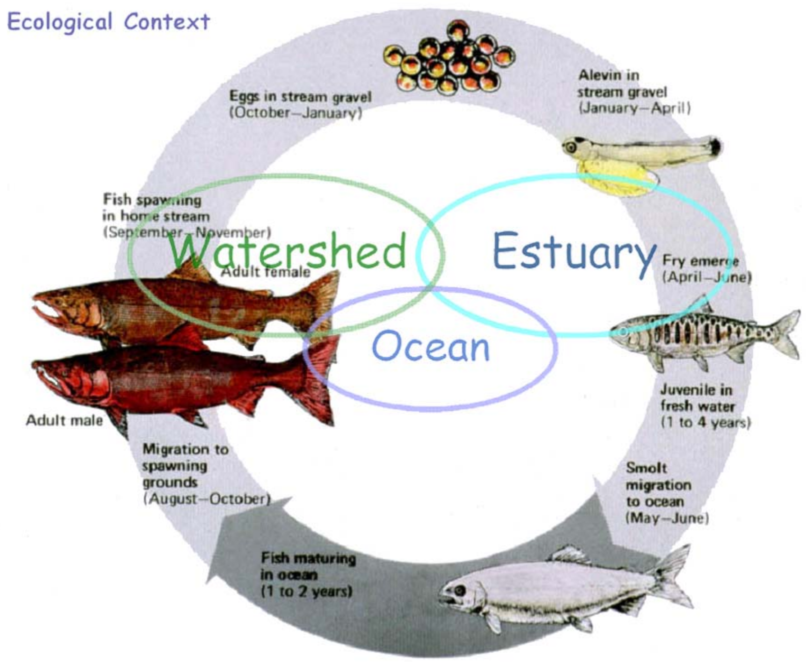
Conceptual Framework for Research Themes and Questions

While identifying the major research themes is essential, having an analytical framework to link and organize scientific research questions is equally important. Salmon life cycle models (Figure 1a) provide the analytical framework for assessing how each of the traditional areas of salmon research (the "four Hs"—Harvest, Hatcheries, Habitat, Hydropower) and other factors can affect Pacific salmon life stages (Figure 1b). Defining viable populations is an important piece needed in evaluating the relative risk of human activities and the potential efficacy of management actions on salmon recovery. NOAA Fisheries has defined four key attributes of a viable salmon population: abundance, productivity (population growth rate), diversity, and spatial structure. The life cycle models and the elements of a viable salmonid population form the basis for an integrated life cycle approach for salmon science at the Center and helps address the scientific challenges in developing sound conservation and recovery plans for a species with such a complex life history.

The framework and life cycle models will be used to help identify critical data gaps, research priorities, and new areas of research. The research priorities will be balanced with those research questions specifically identified by management. As we discuss below, linking the effects of all management actions into a life cycle or ecosystem model is in its early stages and still one of the greatest scientific challenges in salmon recovery efforts.

Past modeling efforts have been of limited utility because a minimum threshold of necessary biological data was unavailable. We believe that the 10 research themes and associated specific research questions below provide the necessary construct to guide research on the specific biological and ecological information needed to improve both the quality and predictive capability of life cycle models. This assures the relevancy of our science to inform decisions on recovery options and sustainable management of Pacific salmon.

A



B

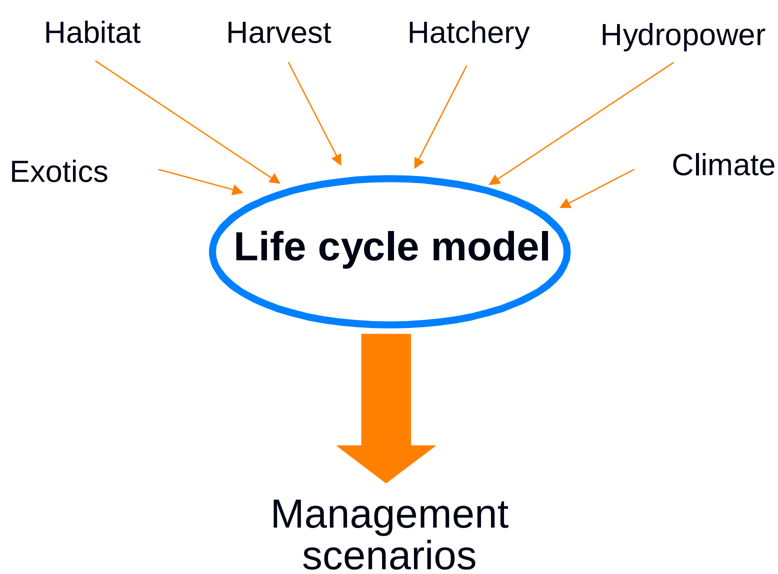


Figure 1. A generalized depiction of the Pacific salmon life cycle (A) and a simplified model of how major risk factors including the "four Hs" feed into life cycle models and ultimately provide scenarios for management options (B). Habitat includes freshwater, estuarine, and ocean habitats.

Ten Salmon Research Themes

The purpose of producing this research plan is to provide a standard against which each research project can be measured. We should ask of any research project whether it substantially addresses at least one of these 10 research themes and associated questions. If not, then the priority of that project needs to be reconsidered. The identification of these priorities is an iterative process that requires periodic refinement of questions through discussion with both scientists and resource managers.

The NWFSC and many research organizations have been working over the last few decades to address research themes that are absolutely essential to improving management of salmon and the recovery of ESA-listed populations. These first five themes include what were historically called the 4Hs (harvest, hydropower, hatcheries, and habitat) plus population viability. No less important for understanding how salmon populations vary in time and space and how they are affected by human activities are the last five themes, which focus on newer areas of research initiated more recently at the Center. These last five themes depend in part on results from the first five and will require long-term research and data collection. A common thread through all themes is the need for information on habitat specific survival and life history diversity.

Below we briefly define the key research themes and the current, specific research questions. Detailed plans to address each theme and associated questions are being developed by various science programs in the Center. Our objective here is to identify the major themes and associated questions that will be the basis for more detailed research plans. Specifically, the 10 research themes are:

1. Salmon Population Biology and Viability

Society is unlikely to continue to allocate funds for salmon restoration unless we provide unambiguous viability goals for management. When these goals are achieved, a population will be considered recovered. This includes defining populations, assessing the viability of these populations, and establishing goals for the number and diversity of populations. In order to establish these goals, a great deal of basic biological and population and evolutionary biological research is still needed, including extensions of existing theory. In the short term, NOAA is taking current science, developing recovery goals, and quantifying the uncertainty around the goals through Technical Recovery Teams (TRTs) composed of scientists and resource managers (more on TRTs is at http://www.nwfsc.noaa.gov/trt/index.html). Although great strides have been made in population biology (e.g., the evolutionary significant unit or ESU concept, the definition of viable salmonid population or VSP, etc.), we must continue to refine and improve our definitions using the latest findings and technologies. Research questions regarding population structure, life history theory, and spatially structured population dynamics are:

- How can the relationship between population abundance, growth rate, and diversity and spatial structure be quantified?

- How can methods of evaluating the viability of populations and groups of similar populations (ESUs) be improved?
- What is the sensitivity of population viability analysis to incorrect assumptions and poor data?
- How does dispersal of individuals among salmon populations or subpopulations affect population viability and diversity?
- How can the viability of mixed populations of wild and hatchery salmon be determined?
- What are the consequences for population viability analysis of making mistakes in defining or identifying populations?
- What are robust monitoring and evaluation protocols to measure salmon status, trends, and recovery?

2. Harvest Management

Fisheries managers around the world have been criticized for failure to manage harvest in a way that prevents overfishing. Criticisms typically leveled against current practices of stock assessment and harvest management include the failure of existing methods to accommodate incomplete and variable data and to account for the effects of environmental fluctuations. For Pacific salmon, these problems are most pronounced in the case of harvest impacts on threatened and endangered ESUs. This has been complicated by the loss of stock-specific exploitation rates provided by coded wire tags (CWT) prior to the mass marking (fin clipping) of all hatchery fish.. Traditional population production models, upon which harvest management theory is based, may not be appropriate for populations with very low population growth or abundance. Methods for linking particular levels of harvest-related mortality to extinction risk have only recently been initiated and they need further development. Better understanding of salmon population dynamics at low to moderate abundance levels is important for evaluating the additional risks that harvest mortality poses to these stocks. Continued development of selective fisheries and harvest methods with lower incidental mortality might lower harvest-related mortality rates of listed ESUs, while at the same time allowing greater flexibility in the harvest of abundant stocks. We need to better integrate harvest into other recovery efforts (habitat, hydropower, hatcheries, etc.) for listed populations. Key questions related to this research theme include:

- What are the effects of incidental fishery mortalities on population viability?
- How can stock or population specific harvest mortalities be estimated or existing estimates be improved?
- What are the effects of selective fisheries on wild salmon populations ?
- How can predictions of run strength and harvest impacts be improved?
- How can sustainable yield harvest rates and escapement goals be achieved?
- What are the impacts of harvest on life history abundance, diversity, and population structure?
- How can planning and assessment tools for harvest impacts be improved?
- What methods of evaluating harvest and escapement goals are appropriate for either recovery or sustainability of populations?

3. Fish Passage and Hydropower

As a result of PIT-tag technology, we are developing a better understanding of the direct effects of hydropower operations on in-river salmon survival. That understanding has played a key role in managing salmon during their residency and migration in the mainstem Snake and Columbia rivers. Important questions remain, especially those concerning the extent of indirect effects (i.e., delayed mortality) of the hydropower operations. Specifically, we need to determine effects of different in-river passage routes (turbine, spill bypass, etc), transportation (barging), changes in migration timing, and flows on the survival, fitness, and life history traits of salmon outside of the migration corridor. More research and further improvements in tagging and other technology are needed to assess the indirect or delayed effects of the hydropower system on fish survival as they move through freshwater and into the estuarine and marine environments. Important questions related to fish passage and hydropower issues include:

- How can direct survival of salmonids migrating through the hydropower system be quantitatively measured and improved?
- What are the indirect and delayed effects of hydro system operations on salmonid survival and fitness?

4. Hatcheries and Aquaculture

There is considerable debate within the scientific community over whether hatcheries and other fish culture facilities help or hinder salmon recovery efforts. The debate is confused by the fact that hatchery operations vary widely in size, rearing practices, and goals. For example, a captive broodstock program has very different goals from a supplementation hatchery or a production hatchery. Moreover, other fish culture facilities such as net-pen rearing of salmon in marine waters may have impacts on listed salmon. Additional information on the influence of hatcheries on the population dynamics, growth rate, and evolutionary fitness of wild fish is clearly a critical need, as well as knowing the impacts of fish culture facilities such as net-pen operations on salmon habitats. The potentially significant impacts are both genetic (reduced fitness due to breeding between hatchery and wild fish) and ecological (reduced survival of wild fish because of large numbers of hatchery fish in the system). Questions related to hatcheries and salmon aquaculture include:

- What are the effects of hatchery releases on the viability of natural salmon populations?
- Under what circumstances can hatcheries help to improve population viability?
- How fit are hatchery salmon and their natural-origin offspring when they reproduce with wild fish?
- What are the long-term genetic consequences of hatchery supplementation?
- What are the effects of hatcheries and other aquaculture facilities on habitat, water quality, survival, and life history diversity of wild salmon populations? (See Theme 7 below.)

5. Habitat and Water Quality

States, counties, water districts, cities, and the regulatory branch of NOAA Fisheries are moving ahead with plans for restoring or protecting freshwater salmon habitats. Unfortunately, we do not know with certainty what these habitat actions are likely to yield in terms of increased salmon abundance, production, or survival. Nor do we understand how ecosystem processes, such as primary production or delivery of wood, water, and sediment, are specifically linked with habitat specific salmon survival and expression of life history diversity. The scientific challenges of linking habitat actions to salmon recovery include: identifying the correct scale of analysis; quantifying the effects of land use practices on ecosystem processes, physical habitat, and water quality; determining the biological effectiveness of restoration efforts at multiple scales; and recognizing that habitats and the processes that create them are dynamic and figuring out how to build that into the model and the plan. It is now becoming clear that restoring physical, chemical, and biological attributes of salmon habitats are all essential to salmon recovery; we must look beyond traditional indicators of habitat quality (e.g., number of pools, water temperature, dissolved oxygen, contaminants) to adequately measure the quality of ecosystems that support salmon. Moreover, human population growth and climate variability need to be incorporated into assessments of habitat conservation and restoration efforts.

In addition to traditional physical indicators, water quality and impacts of contaminants on fish health and survival are an important part of habitat investigations. There is a need for continued and new evaluation of the effects of contaminants, pesticides, and other pollutants on the survival, fitness, and abundance of salmon and their prey. A watershed-scale view is needed of both physical and “chemical” (e.g., contaminants and nutrients) habitat, including examination of cumulative effects of multiple stressors. Important questions related to salmon habitat can be divided into three categories based on physical habitat, water quality and contaminants, and integrated effects of all freshwater and estuarine habitat factors.

Physical habitat questions include:

- What are the relationships between habitat attributes at various scales and salmonid production, survival, life history expression, and population viability?
- What are the effects of human-induced changes on ecosystem processes, habitat, salmon survival, abundance, and life history types?
- What are the restoration strategies that restore natural processes critical for forming habitat and lead to measurable increases in fish survival, abundance, and life history diversity?

Water quality and contaminants questions include:

- What are the effects of toxic substances on salmon survival, abundance, and life history diversity? (See Theme 4 above.)
- What are the lethal and sublethal effects of various toxic substances on salmon fitness?

Integrated effects questions include:

- What are the cumulative effects of multiple habitat stressors in a watershed on fish health and survival?
- What are the effects of various habitat impacts on trophic production?

6. Ocean and Estuarine Ecology

Little information exists on salmonid residence in, use of, and survival in various estuarine and marine habitats. However, the results of actions related to Themes 2 through 5 often depend on estuarine and marine conditions and salmon survival in these habitats. For example, the ecological impacts of releasing large numbers of hatchery fish may depend on ocean conditions and the resultant productivity available to support salmon growth. Similarly, the sublethal effects of habitat degradation or hydropower operations may depend on marine conditions or the presence of other species in the system. If research directed at Themes 2 through 5 does not explicitly consider these contingencies, then results may either be misleading (because the data are collected under only one set of circumstances) or erroneously equivocal (because variability in results is interpreted as unexplained variance and results yield nonsignificant statistical metrics). Investigating the interactions between anthropogenic and environmental risk factors will require crossing traditional disciplinary boundaries (e.g., estuarine vs. freshwater ecology). Moreover, this broad-scale research will require strengthening partnerships with other entities along the West Coast that are currently conducting oceanographic and climate research (see also Theme 8.). Specific questions related to estuaries and oceans include:

- Where do juveniles reside during the first few months of estuary/ocean residence?
- How do we best measure growth and fitness of salmonids in different estuary/ocean habitats to identify survival bottlenecks?
- How do variations in health and physiological condition of salmonids affect their growth and survival in estuaries and the ocean?
- What are the effects of different estuarine and marine habitats and habitat conditions on salmon survival and life history expression?
- What are the impacts of diseases and parasites in estuaries on growth and survival of fishes?
- To what degree is juvenile survival limited by predation by birds and mammals rather than growth limitation by poor estuarine and ocean feeding conditions?

7. Nonindigenous Species

Salmon interact with a broad range of species, and the abundance or even presence of many species in salmon habitats have been severely altered by human activities. For example, since the late 1800s, over 20 species of predatory fish have been introduced into the Columbia River Basin. America shad (*Alosa sapidissima*) were introduced into the Columbia River in 1885 and now number several million, representing one of the few growing fish populations in the basin. Atlantic salmon (*Salmo salar*), which are increasingly used for net-pen aquaculture on the West Coast, could pose a risk to wild Pacific salmon if they introduce harmful exotic pathogens or escape and establish naturally reproducing populations. Exotic species exist not only in the freshwater environment, but also in estuarine, nearshore, and marine environments. For example, the spread of Atlantic smooth cordgrass (*Spartina alterniflora*) throughout the West Coast may substantially alter estuarine and nearshore ecosystem functioning and processes. Many ecologists have suggested that the "exotic species problem" is one of our greatest environmental hazards. An evaluation of the effects of individual and multiple exotic species on entire ecosystems is needed. Specific research questions related to exotic species include:

- What are the effects of individual and multiple exotic species on ecosystem processes and functions?
- What are the effects of single and multiple exotic species on salmon viability and what factors appear to exacerbate or mitigate these impacts?
- What are effective methods for eliminating or limiting negative impacts of exotic species?
- Can we identify, limit, or prevent future invasions of exotic species and how do changes in habitat affect the potential for invasions?
- What are the cost/benefits of eradication/control of nonindigenous species versus nonintervention?

8. Climate Variability and Change

Pacific Decadal Oscillation, El Nino, and other climate events can have profound effects on hydrology, wildfires, physical processes, ocean conditions, and biota. Regardless of whether changes in climate are the result of natural processes, human induced, or reflect longer term global climate shifts, they have had and will continue to have a significant effect upon salmon and their ecosystems. A critical question is how to incorporate the effects of climate variability and change into salmon viability estimates and recovery planning efforts. For example, should recovery goals place a premium on genetic diversity so that evolutionary flexibility is maximized? Should higher freshwater biological productivity be required to compensate for potentially reduced oceanic biological productivity? To answer these questions our salmon biologists will have to develop stronger collaborations with oceanographers, hydrologists, and climate specialists than has traditionally occurred. Given that the NOAA Weather Service is a sister agency to NOAA Fisheries, we are in a particularly good position to work collaboratively with NOAA climate scientists and hydrologists to apply their analyses to salmon viability. In addition, we need to examine the effects of climate change at multiple scales (e.g., watershed, regional, and western Pacific scales). Tying salmon ecological risk analyses into large collaborative partnerships with universities and other research entities offers unique and powerful opportunities for this line of research. Key questions related to climate and associated hydrologic changes include:

- What features of climatic cycles and trends have the greatest influence on salmonid survival, abundance, and life history diversity and through what mechanisms?
- What is the effect of changes in climate and precipitation on ecosystem processes, stream hydrology, and quantity and quality of salmon habitats?
- In order to accommodate changes in climate, do we need more subpopulations of salmon than we might otherwise require?

- Can we anticipate impacts of climate change on salmon prey and predators that might in turn profoundly alter salmon population dynamics? (See also Theme 10.)

9. Socioeconomics and the Human Dimension

Biological information determines whether or not a species is federally listed under the ESA. Yet the management and recovery of those species takes place in an environment where humans dominate and the other species are but a small part. Understanding the social and economic characteristics of the environment is a necessary part of designing effective management and recovery programs. Moreover, while natural sciences can inform policy decisions, the ultimate decisions are often based on human factors. Thus social science analyses are needed to complement natural science research. These analyses include answering the following questions:

- What are the social, economic, and cultural characteristics of communities dependent on fishing?
- How can biological and economic data be used to determine the cost-effectiveness of salmon recovery actions?
- What are the social and economic values of recovering salmon populations and restoring the ecosystems upon which they depend?
- What social and economic institutions and incentives are most effective for promoting salmon recovery?

Because NOAA Fisheries is responsible for only some of the actions needed for the successful management and recovery of salmon populations, the choice to use social science research is only partly in the hands of the agency. Nevertheless, encouraging a deeper scientific foundation for management and recovery actions by embracing the social sciences as integral to the “science” of salmon is in the hands of NOAA Fisheries.

10. Cumulative Effects

This last research theme, which integrates components of all the others, is the most difficult. It is also arguably the most important, because without a comprehensive model (or models) there is no way to link the previous nine research themes and evaluate their relative and cumulative effects on salmon survival, fitness, viability, and diversity. Examining species one at a time is both impractical (because there are too many species of concern) and possibly erroneous (because ecosystem processes might degrade while populations lag behind and still appear healthy). Consequently, there is widespread call for ecosystem-level approaches to science, management, and multispecies recovery plans. Some agencies, including NOAA have made ecosystem-based management a goal (details available at http://www.spo.noaa.gov/strplan.htm). Moreover, because of the complex and migratory salmon life cycle, one cannot simply identify one particular ecosystem or part of an ecosystem that needs to be protected. This requires that ecosystem analysis and management for salmon must consider freshwater, estuarine, and ocean ecosystems in recovery strategies, and that their respective impacts on salmon be considered in the context of a life cycle model.

While population biology will be a key component of effective salmon management, we need to ensure that the effort is guided by hypothesis-driven science and we may need to solicit tools from other disciplines such as geography, terrestrial, landscape, and spatial ecology. Before a model integrating all factors at an ecosystem level can be developed, a detailed plan is needed. Currently, Center scientists are employing a Leslie matrix and other life cycle models to link the effects of multiple risk factors and assess their cumulative effect on salmon populations. We are in the process of testing these models and redefining our research plan for this theme. It will clearly need to integrate components of previous themes and questions. The formulation of detailed questions is in an early stage, but includes:

- What models are most effective for combining effects of multiple stressors?
- What types of data are needed from the other themes to improve or populate these models, such as how do fish movement and behavior affect parameter estimates used in models?
- What are the effects of various risk factors (identified from previous themes) on overall viability of salmon populations?
- What are the effects of multiple stressors (e.g., fishing, hatcheries, habitat degradation) on evolution of life history traits in salmon populations?
- How can societal and economic considerations (Theme 9) be incorporated into these ecosystem or life cycle models?

Challenges Common to All Themes

Two major shortcomings that are important for the 10 research themes remain to be overcome. First, broad-scale manipulations that impact entire populations need to be performed with testable hypotheses and rigorous monitoring in order to reduce uncertainty about population-level impacts. Second, region-wide monitoring currently does not exist and basic data of known quality on salmon abundance and habitat are not systematically reported and available. That lack of integrated monitoring, systematic reporting, and data availability limits the potential to address several of the themes outlined in this document.

Large-Scale Experiments

Research at the scale of entire ecosystems uses several approaches, including theory, long-term observational studies, comparative studies, and, on occasion, experiments. Manipulative, landscape-scale experiments are a means to test specific hypotheses concerning salmon recovery, but in most situations such experiments are impractical, if not impossible. Planned management activities (e.g., dam removal, hatchery closure, habitat management), however, provide opportunities to conduct such experiments. While such management actions are rarely designed as “good” experiments, they are unique opportunities to address key uncertainties. To be of value, the goals of the management actions must be clearly stated so there is a clear statement of the hypothesis that can be tested. Scientists must have a role in the planning and execution of these actions, explicit experimental designs must be used that incorporate the need for treatments and controls across a gradient of sites, and there must be the foresight to identify control sites and collect critical “before” data at both treatment and control sites. Most previous studies suffer from lack of adequate spatial and temporal replication. Given the extent of the salmon problem, there is an unprecedented opportunity to replicate management treatments across many watersheds and conduct some of the largest and most powerful ecological experiments ever undertaken.

No single organization can effectively carry out these types of experiments. A way to identify of research requirements and an institutional framework for conducting research are needed. The research community needs to identify opportunities, develop effective partnerships with multiple institutions, and leverage multiple resources to encourage these large-scale experiments. To address the need for broad-scale experiments, the Center is collaborating with other agencies, universities, and research organizations, and we have initiated several projects aimed at addressing large management actions or manipulations. For example, we are currently examining the effects of dam removal in the Elwha River and examining the effects of nutrient enrichment on the biological productivity of several watersheds in the Salmon River basin in Idaho. We are also working closely with several agencies to implement watershed-wide monitoring in several watersheds in Washington and Oregon. However, these experiments are only the beginning and many more such experiments are urgently needed to test critical hypotheses upon which potentially successful salmon management and recovery options will be based.

Better Data Management and Monitoring

Conducting large-scale experiments will also require addressing the need for well coordinated monitoring and evaluation both at coarse and fine spatial scales. While several agencies are working hard to integrate monitoring, there currently is no region-wide coordination of monitoring or a network of databases that provides access to data, nor are there systematic reporting standards or protocols. A great deal of the basic data is not systematically collected, documented, organized, or available and have not been subjected to adequate assessment of data quality. Many data sets have insufficient data collection to be useful for scientific assessment. For example, the viability of most wild populations cannot be assessed because hatchery-origin fish intermingle with fish on spawning grounds, making it difficult to estimate wild recruit-per-spawner ratios.

In fact, the lack of statistically based long-term monitoring and high quality data have greatly limited the ability to evaluate the effects of human activities and natural processes on salmon viability and trends. This lack limits development of robust, full life cycle models and limits the strength of the foundation for addressing many of the 10 key research themes. Without rigorous monitoring and evaluation we will not know the effectiveness of salmon recovery and management actions. The quality of regional monitoring data will only be as good as the available data management systems. High quality data are of limited value unless multiple parties can easily access it, data standards and protocols are in place, and the data are well documented. Solutions to these data management problems require a comprehensive, region-wide approach and a common commitment across multiple entities to have data quality assurance through consistent or compatible sampling methods, data collection, standards, and management protocols. While state and federal agencies and tribes have worked to improve consistency of data collection and develop compatible databases, most of this effort to date has been ad hoc, incremental, and without overall planning or cost sharing agreements to leverage the opportunities. Efforts are underway to take a systematic approach to addressing regional data management needs.

As with large-scale experiments, coordination and partnerships among multiple agencies are the only viable options to develop a regional information network at the geographic scale that is needed to evaluate coast-wide salmon recovery. Both the availability and the quality of data are important for the NWFSC and other research entities to conduct rigorous analyses that measure the effect of management actions (experiments) on salmon viability. Thus the Center will continue to work with other agencies to improve the quality, quantity, and reporting of basic salmon monitoring data in the Pacific Northwest and address this pressing need for better data and data management. Success in this area will greatly improve our ability to conduct rigorous scientific research on many of the research themes and questions.

Detailed Research Plans for Each of the 10 Themes

The 10 research themes we have identified are overarching areas of research that will be relevant for several years. While these broad themes are needed to guide prioritization of research, greater specificity is needed at the project level. Although all research projects will address at least one of the themes or associated questions, more detailed hypotheses are needed to guide the direction of the Center's divisions and research programs and teams, as well as to guide the development of new teams to tackle interdisciplinary research.

We are currently developing detailed research plans by division or program. These plans will include a summary of the questions being addressed, how the current research addresses these questions, what are the specific hypotheses being tested, short and long-term research priorities, and future research directions. Each of these plans will be updated periodically (1–3 years) to insure it addresses the most pressing research needs and incorporates new and innovative techniques and ideas. What we present in this document serves as the unifying framework upon which we have built and will continue to build specific and tractable research programs. This strategic research plan will be updated periodically to reflect scientific advances as well as changes in agency priorities.

To assure that our research is relevant to agency resource managers, we developed this list of themes and associated questions with input from the NOAA Fisheries Northwest Regional Office. We will meet periodically with the Regional Office to update our research objectives and priorities. Addressing the research themes and questions outlined in this plan is dependent upon strengthening our existing partnerships and creating new ones to work collaboratively to answer these questions. This is not only essential because of the scale of the questions and the actual cost of the research, but also the most efficient use of taxpayer dollars.